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Well Correlation and Petrophysical Analysis, a Case Study of "Rickie" Field Onshore Niger Delta

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-----ABSTRACT-----
*A suite of geophysical wire-line logs from an oil field inNiger delta have been examined and analyzed. The logs include gamma ray(used for the identification of lithology), resistivity/conductivity(used for the delineation hydrocarbon bearing reservoirs) and neutron (NPHI)and formation density(**RHOB**) tools (used to map out gas bearing zones). Lithostratigraphic correlation sections of four wells (R_1, R_2, R_3 and R_4) depict that the subsurface stratigraphy is that of sand – shale interbedding. Three prominenthydrocarbon bearing reservoirs (L,P andS), located at depths of 9,650ft (2,943m), 10,650ft (3,248m) and 12298ft (3935m)were identified and mapped. Petrophysical parameters of the reservoirs which included porosity, hydrocarbon saturation, volume of shale, formation resistivityand formation factor were computed. The reservoirs have averaged porosity of 30.2%, water saturation 19.7% and hydrocarbon saturation of 80.3%.These research findings will contribute immensely in oil field development programmes.*

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I. INTRODUCTION

Generally the earth constitute of rocks that varies in properties (i.e. chemically and physically). The complexity of the earth due to it inhomogeneity impedes the ability to explore it resources maximally. Hence, the ability to understand the physical and chemical properties of the earth has been in use at greater extents for the detailed study of the subsurface and it constituents. A potential tool in use has been the contrast in physical properties of the subsurface constituents. The earth's properties include: magnetic susceptibility, dielectric constants and gravity constants, elastic properties among others. Investigation of the earth's interior using geophysical methods, involves taking measurement at or near the surface of the earth for analysis that can expose both vertical and lateral variations of the physical properties of the earth's subsurface. The significance of hydrocarbon to the present day economy has been called for so many methods that are geology and geophysics based. The uses of exploratory wells that are drilled through prospective geological structures have been of greater assistance in evaluating the hydrocarbon potential of so many locations. In order to know the quantity of hydrocarbon accumulation in reservoir rocks (sandstone, limestone or dolomite), some basic petro physical parameters must be evaluated. These parameters include porosity, thickness and extent of formation, hydrocarbon saturation and permeability. Logs ranging from electrical, nuclear and acoustic have been in use for deriving these parameters.According to Asquith and Krygowski (2004) well logs are used to correlate zones suitable for hydrocarbon accumulation, identify productive zones, determine depth and thickness of zones, distinguish between gas, oil and water in a reservoir and to estimate hydrocarbon reserves. Basically this project utilizes a suite of borehole geophysical wire lines logs for the evaluation of the hydrocarbon potential of an oil field in Niger Delta.

II. LOCATION AND BRIEF PETROLEUM HISTORY OF THE STUDY AREA

The study area is located within the onshore continental margin, south west Niger Delta. It occupies an area enclosed by the geographical grids of latitude 5.3^0 and 5.4^0N and longitude 6.0^0 and 6.2^0E.Shell-British Petroleum brought the first well on stream in 1958 at 5,100 barrels per day. From 1958 until the Biafran War in 1967, exploration and production increased in Nigeria. The war curtailed both activities until its end in 1970, when world oil prices were rising and Nigeria again could benefit economically from its petroleum resources in the Niger Delta. The Delta is rich in both oil and gas. The general consensus is that the most effective source rock, in Niger Delta sequence is the marine shale of the Akata Formation and the shale interbedded with the paralic sandstones of the Agbada Formation and that they have both yielded oil and gas. The Akata Formation has yielded about 97 billion bb1 of reserved oil while the Agbada Formation has yielded only about 21 billion bb1. These estimates suggest that the Akata Formation is by far the most important source rock, although its expulsion and migration efficiency is much lower than that of the Agbada Formation (Ejedawe 1981).

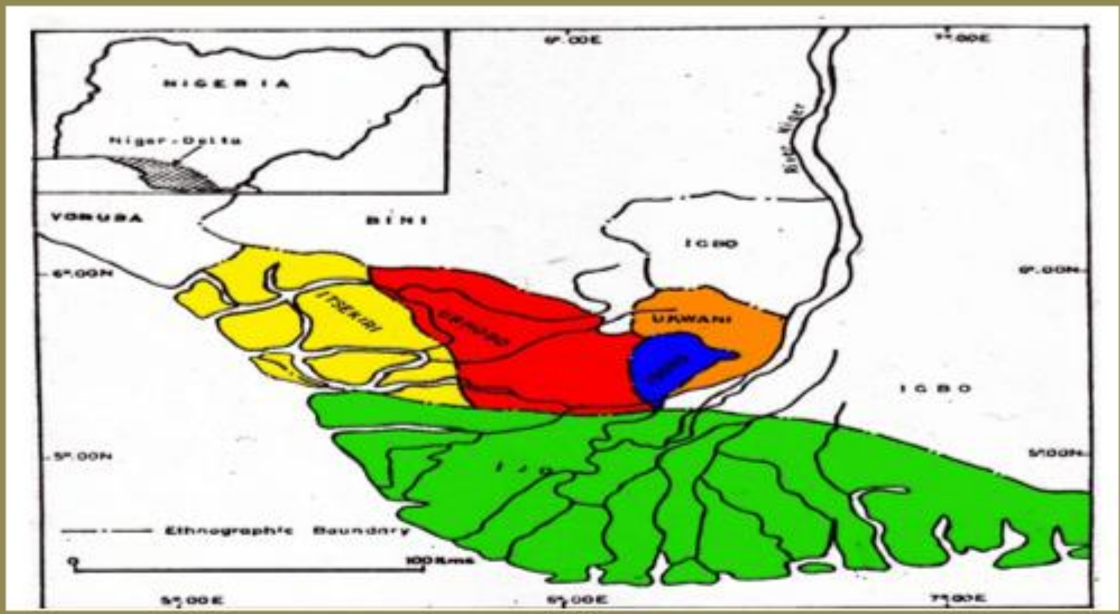

Figure 1: Regional setting of Niger Delta

III. METHODOLOGY

Lithology Identification (Correlation Panel)was the first major evaluation that was carried out in this research.

The gamma ray log measures natural radioactivity in the formation. Shale free sandstones have low concentration of radioactive materials, and give low gamma ray readings. Therefore increase in shale content on the other hand gives high gamma ray response. Based on this principle, a general lithostratigraphy of the study area consisting of alternating sand and shale lithologyhave been carefully evaluated across the wells using the defined gamma ray response. The studied units lie within a depth range of 7400ft (2368m) to about 11300ft (3616m)

Based on the suite of logs used for this research, the estimated parameters include Gamma ray index (**I_{GR}**), Volume of shale (**V_{sh}**), True formation resistivity (**R_t**), Water saturation (**S_w**), Hydrocarbon saturation (**S_h**), Formation factor (**F**), Bulk volume water (**BVW**) and Porosity (**Φ**).With the aid of Neutron **(NPHI)** and Formation Density **(RHOB)** tools, distinguishing the oil, water and gas zones was also carried out.

Volume of Shale (V_{sh}). Before computing the volume of shale, gamma ray index was first calculated with the aid of gamma ray log, using equation 1

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (1)$$

Where:**I_{gr}**= Gamma ray index, **GR_{log}** = Gamma ray reading of formation, **GR_{min}** = Minimum gamma ray (clean sand or carbonate) and **GR_{max}**= Maximum gamma ray (Shale). Niger Delta reservoirs are made of unconsolidated sandstones. Therefore, equation 2for tertiary unconsolidated rocks was used in the computation of the values obtained for volume of shale.

$$V_{sh} = 0.83\left(2^{(3.7 \times IGR)} - 1.0\right) \quad (2)$$

(Dresser Atlas 1979)

True Resistivity (R_t), Based on the logs that are available for this work, the values obtained for formation true resistivity were read out from points of maximum deflection of resistivity log signature on the reservoir and averaged.

Water Saturation (S_w) this is the water held in the pore spaces by capillary forces. It is determined using the equation 3

$$S_{wirr} = \sqrt{\frac{F}{2000}} \quad (3)$$

Where F=formation factors and was determined using equation 4

$$F = \frac{a}{\Phi^m} \quad (4)$$

Where Φ = porosity**m** = Cementation exponent (usually 2 for sands) **a** = tortuosity factor (taken as 0.62)
Bulk Volume Water (BVW) This is the product of the formation's water saturation and porosity.

$$\text{BVW} = S_W \times \Phi \quad (5)$$

Where;Sw = Water saturation of Uninvaded zone and Φ = Porosity.
Porosity (Φ), the computation of porosity was made possible through the use of density log. Readings were taken directly from the log. The said values were then computed using;

$$\Phi_{den} = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \quad (6)$$

WhereΦ_{den} = density derived porosity,ρ_{ma} = matrix density,ρb= formation bulk density, ρf = fluid density (which was taken 1.0 in this research work).

Water Saturation (S_w). Thewater saturation values were read out at intervals and averaged from the available water saturation log at point of minimum deflection adjacent to the reservoir of interest.
Hydrocarbon Saturation (S_h) is the fraction of pore volume occupied by hydrocarbon and it is dependent on water saturation. It is calculated thus:

$$S_h = 1 - S_w \quad (7)$$

Where: Sw = water saturation and Sh = Hydrocarbon saturation.

IV. DATA PRESENTATION AND DISCUSSION OF RESULTS

The evaluation of the hydrocarbon potential of an area is dependent upon a range of factors that are geology and geophysics based. The basic understanding of the formation and critical evaluation and interpretation of geophysical/geological data and features are not negligible. Constructed correlation panel were made available to depict the general stratigraphy and subsurface geometry of the rock strata. Here in this research, 4 wells (**R_1**, **R_2**, **R_3** and**R_4**), were evaluated. Reservoir parameters such as Permeability (K), Porosity (Φ),Water saturation (S_w), Hydrocarbon saturation (S_h), Bulk Volume Water (**BVW**), Irreducible water saturation (**S_{wiir}**), Volume of shale **(V_h)**, (TABLES 1, 2 and 3) have been carefully analysed as a way to describe and evaluate the hydrocarbon potential and economic viability of "Rickie" oil field.

Reservoir Analysis

Table 1: Results of the Petrophysical Analysis of Reservoir L.

WELL	$Thickness(Ft)$	(Φ) %	(V_h)%	(S_w)%	(S_h)%	(BVW)%	(S_{wiir})%
R_1	**33**	**30**	**9**	**13**	**87**	**10**	**6.0**
R_2	**207**	**30**	**8**	**100**	**00**	**10**	**6.0**
R_3	**31**	**30**	**35**	**30**	**70**	**10**	**5.5**
R_4	**55**	**32**	**4**	**15**	**85**	**11**	**6.0**

Across the wells, reservoir Lshows an average porosity of 30.5% and Volume of shale of 14%. In **R_1**, **R_2**and **R_4** it has an averaged hydrocarbon saturation of 80.7%. **R_2** is 100% water saturation. The wells show almost constant values of Bulk Volume Water and irreducible water saturation. This is suggesting homogeneity of the zone as regards irreducible water saturation.

Table 2: Results of the Petrophysical Analysis of Reservoir P

WELL	$Thickness(Ft)$	(Φ) %	(V_h)%	(S_w)%	(S_h)%	(BVW)%	(S_{wiir})%
R_1	99	30	41	19	81	10	6.0
R_2	97	28	9	95	05	10	6.0
R_3	90	32	12	22	78	10	6.0
R_4	50	32	30	82	18	15	6.0

Across the wells, reservoir P shows averaged porosity and volume of shale of 30.5% and 23% respectively. $\mathbf{R_1}$and $\mathbf{R_3}$ shows averaged hydrocarbon saturation of 79.5%.The values of hydrocarbon saturation in $\mathbf{R_3}$and $\mathbf{R_4}$ are not inviting at all.

Table 3: Results of the Petrophysical Analysis of Reservoir S

WELL	$Thickness(Ft)$	(Φ) %	(V_h)%	(S_w)%	(S_h)%	(BVW)%	(S_{wiir})%
R_1	103	30	17	18	82	10	6.0
R_2	97	29	14	32	68	10	6.0
R_3	75	27	06	06	94	2	7.0
R_4	113	32	05	95	05	2	7.0

Across the wells, reservoir S shows an averaged porosity of 29.5% and Volume of shale of 10.5%. In $\mathbf{R_1}$**,** $\mathbf{R_2}$ and$\mathbf{R_3}$ it has an averaged hydrocarbon saturation of 81.3%. $\mathbf{R_4}$ shows little hydrocarbon saturation. $\mathbf{R_1}$and $\mathbf{R_2}$show constant values of Bulk Volume Water, while $\mathbf{R_3}$and $\mathbf{R_4}$values also have the same values. If the values for Bulk Volume Water, calculated at several depths in a formation, are constant or very close to constant, they indicate thatthe zone is homogenous and at irreducible water saturation **(S_{wirr}).** When a zone is at irreducible water saturation, water captured in the uninvaded zone will not move because capillary forces hold it. Thus, hydrocarbon from a zone at irreducible water saturation should be water-free (Morris and Biggs, 1967). Also, low bulk volume water values across reservoirs are an indication of high hydrocarbon potential.

Reservoirs Correlation

The alternation of sands and shale in various proportions and thicknesses within the evaluated depth conforms to that of the Agbada formation. The evaluated depth and the thicknesses of the various overlaying shale units, suggest a comfortable room for accumulation of matured hydrocarbon- prospective sequence in the studied area. The thickening of the lithilogic (figure 2) unit at one end with subsequent thinning at the other end could be as a result of delay in depositional periods or different in the volume of sediments deposited per time. From the correlation panel there are series of synthetic and antithetic faults that are closing up on each other, forming closures and indications of rollovers and collapsed crest as explained by Doust and Omotsola (1990). Rollover anticlines are good traps for hydrocarbon. Therefore the trapping mechanism is assisted by the faults and the anticlinal structures which collectively form the structural closures. Obviously the reservoirs are juxtaposed against shale; hence the reservoirs are structurally control. They have good seals /cap rocks and traps. The presence of hydrocarbons in these identified traps is confirmed using wire-line logs(Kearey and Brooks, 1991).

Gas Bearing Zones

Figure 3 shows the depth of occurrence of gas in the reservoir. The presence of gas in a formation leads to a reduction in neutron porosity with a corresponding increase in density porosity. Thus an increase in contrast between these logs (Neutron **(NPHI)** and Formation Density **(RHOB)** was picked as an indication of gas presence in the sand unit, while closeness in the logs signature shows that the reservoir sand is oil-bearing. Consequently, Gas-Up-To **(GUT)** and Gas-Down-To **(GDT)** were also delineated between 10600ft and 10700 ft in R_3.

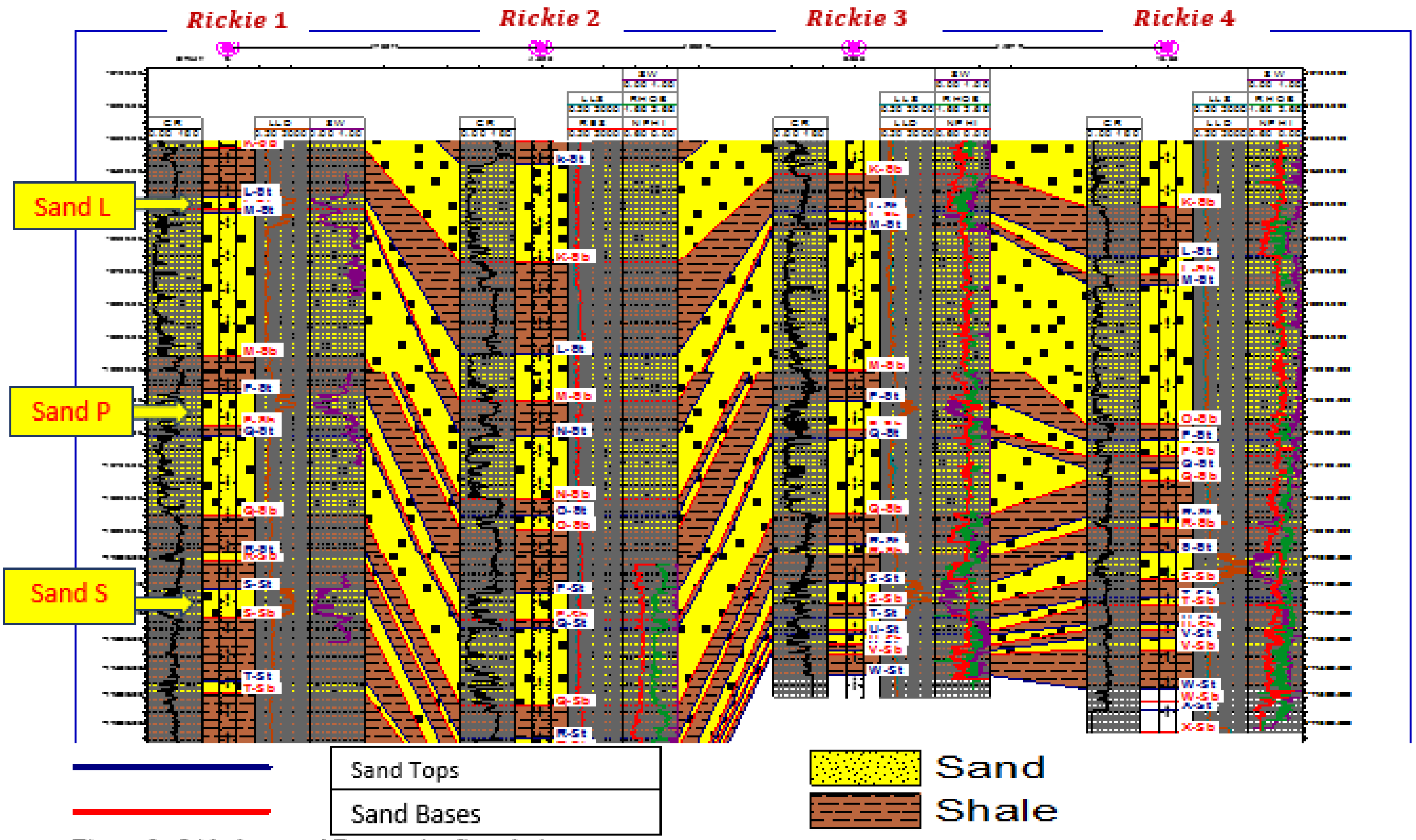

Figure 2: Lithology and Reservoirs Correlation.

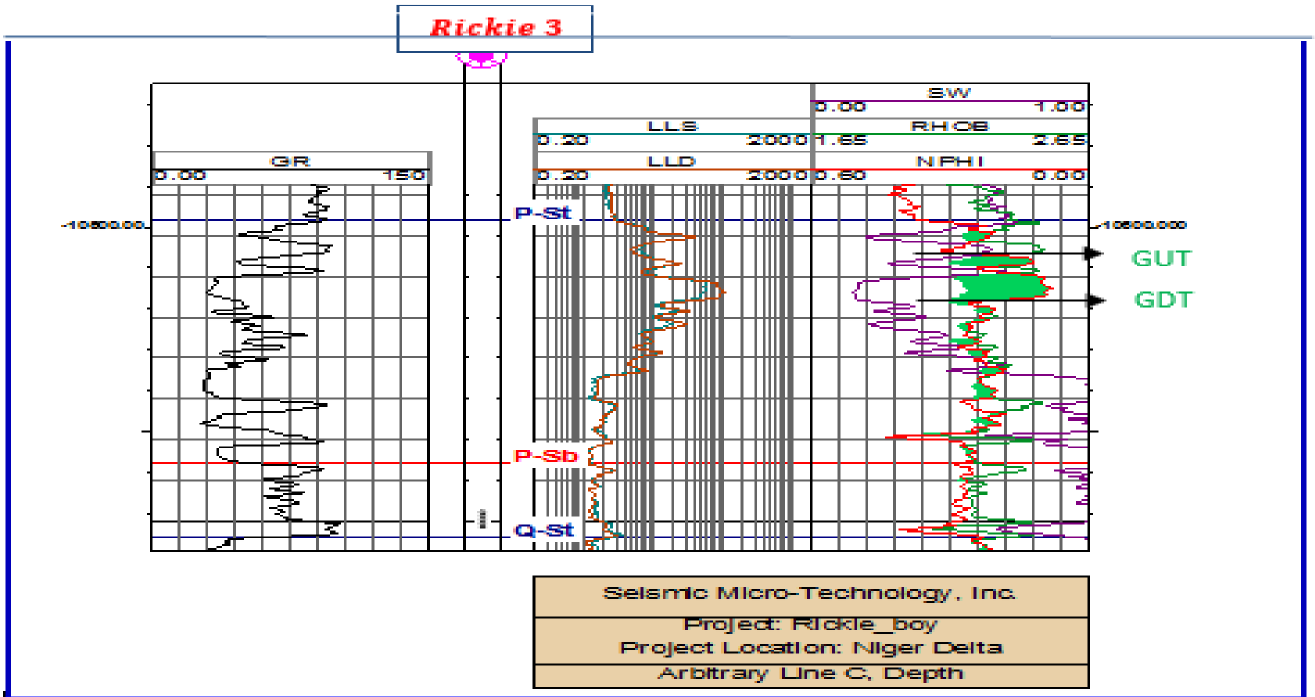

Figure 3: Oil-Gas-Contact with respective Gas-Down-To (GDT) and Gas-Up-To (GUT).

V. CONCLUSION

Neutron, density, gamma ray, resistivity/conductivity logs were employed in the analyses and examination of an oil field in western Niger Delta. Four wells, R_1, R_2, R_3 and R_4 were considered. Lithostratigraphic correlation section of these wells depicts that the subsurface stratigraphy is that of sand shale interbedding.Three hydrocarbon bearing reservoirs (L,P and S) of varying thicknesses were identified and mapped at the depthsof 9,650ft (2,943m),10,650ft (3,248m) and 12298ft (3935m) respectively.Across the wells, reservoir Lshows an averaged porosity of 30.5 % and Volume of shale of 14%. In $\mathbf{R_1}$, $\mathbf{R_3}$and $\mathbf{R_4}$ it has an averaged hydrocarbon saturation of 80.7%. $\mathbf{R_2}$ is 100% water saturated.Reservoir P shows averaged porosity and volume of shale of 30.5% and 23% respectively. $\mathbf{R_1}$and $\mathbf{R_3}$ shows averaged hydrocarbon saturation of 79.5% the reservoir is not economically viable in $\mathbf{R_2}$ and $\mathbf{R_4}$ at all.Reservoir S shows an averaged porosity of 29.5% and Volume of shale of 10.5%. In $\mathbf{R_1}$, $\mathbf{R_2}$ and$\mathbf{R_3}$ it has an averaged hydrocarbon saturation of 81.3%. The reservoir is not yielding well in $\mathbf{R_4}$.

VI. RECOMMENDATION

It is therefore recommended that 3-D seismic data should be incorporated to allow for detailed and complimentary study of "Rickie" field. This will give room for the generation and analyses of 3-D images that will show more revealing details of the geometry of the geologic features and also the area extent with which volumetric reservoir estimations can be calculated.

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BIOGRAPHY

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